The Present and Future of Particle Theory

Presentation to P5 for the DPF Committee on the Future of Particle Physics (K. Babu, C. Csaki, S. Dawson, L. Dixon, S. Gottlieb, J. Harvey, D. Whiteson) by M. Dine, December 2, 2013

Panel Charge

The DPF Theory Panel was formed with the goal of understanding both the scientific opportunities of the next decade, as well as the challenges involved in sustaining a first-class program in the U.S.

Specifically, the panel's charge included:

- Enumerate areas of opportunity in particle physics theory research in order to set forth a vision for theoretical high energy physics for the next several years.
- Establish a range of funding needs for individual PI's to sustain an effective program (students, postdocs, travel, summer salary, equipment needs).

To address these questions, we solicited comments and suggestions from the community, held town meetings at the BNL and KITP pre-Minneapolis workshops leading up to the main meeting in Minneapolis, and held two parallel sessions and a plenary session in Minneapolis.

Theory: An Essential Element of the Particle Physics Enterprise

- Defines many of the questions and issues in the field, and helps set direction for the experimental program
- Provides crucial support for the experimental effort
- An area in which the U.S. has historically been, and remains, a leading force.

The value of theory

- European Strategy for Particle Physics
  - "Theory is a strong driver of particle physics and provides essential input to experiments…..Europe should support a diverse, vibrant theoretical physics programme, ranging from abstract to applied topics…"
- U.S. experimental physicists:
  - "We, the undersigned experimental high-energy physicists, believe that a strong experimental high-energy physics program requires a vibrant theoretical physics community in the United States…."
  - http://amanda.uci.edu/~daniel/theory_letter.php

What's at Stake: Progress in Theory in Recent Years

- Support for experimental program: huge leaps in QCD calculations, Monte Carlo event generators
- Lattice gauge computations of hadronic spectra and matrix elements with precision and controlled errors
- Benchmark models for new physics (supersymmetry, warped dimensions, composite Higgs, multi-Higgs models…)
- Growing range of dark matter models and corresponding experimental signatures
- Models for inflation, dark energy
- Deepening understanding of quantum field theory, string theory – keys to fundamental understanding

Scientific challenges and areas for progress: some exposed by experiment, but many by theory:

- Explanation of the hierarchy?
- Origin of the parameters of the SM?
- Unification of the strong and electroweak forces?
- Strong CP problem? Axions? Axions as dark matter?
- Repetitive generations, hierarchical structure of the masses and mixings of the quarks and charged leptons? Why a very different pattern for neutrinos?

- What is the energy scale associated with the generation of neutrino mass? Are neutrinos their own anti-particles?
- What phenomena might account for the baryon asymmetry of the universe? Might they be accessible to experiments at the Energy or Intensity Frontiers?
- Candidates for the dark matter?
- What is the origin of the dark energy? Why is it just becoming important at the present epoch of the Universe?
- What caused the inflationary epoch, and how did the Universe end up in its current state?
- What is the nature of the quantum theory of gravitation?
- From what set of principles or structures do the laws of nature originate?

These questions will drive much of the experimental program on all three frontiers for the next decade, and at the same time, they will remain the subjects of intense theoretical investigation. The exploration of these questions is our mission as particle physicists, and is what makes particle physics exciting to anyone who encounters it.

Conclusions

Our basic conclusions and recommendations can be simply summarized:

The U.S. should maintain a vigorous research effort in theoretical particle physics, ranging from perturbative and non-perturbative QCD studies, to collider phenomenology, to model building, cosmology, and research in foundational areas.

Resources required to sustain the theory program

Cuts in funding at DOE and NSF have significantly affected the theory effort already, and further adverse impacts are to be expected. Particular areas of concern:

- postdoctoral fellow support
- student support
- PI, postdoc and student travel
- Summer support for university faculty research (current caps affect principally very senior researchers and are helping to protect students and postdocs, but further cuts could do serious damage)

Areas of Concern

The U.S. funding agencies anticipate significant future reductions in funding for theoretical physics. In FY 2013, support for particle physics in the NSF was cut by 10-12%. The DOE is facing a declining budget and is increasing the fraction of its budget devoted to new experimental and accelerator projects at the expense of research funding. Many strong DOE funded groups received 10% or larger cuts in the recent comparative review rounds.

Unlike many elements of the experimental effort, theoretical research does not lend itself to ``project" designation, so the impact of this shift on theory is more pronounced.

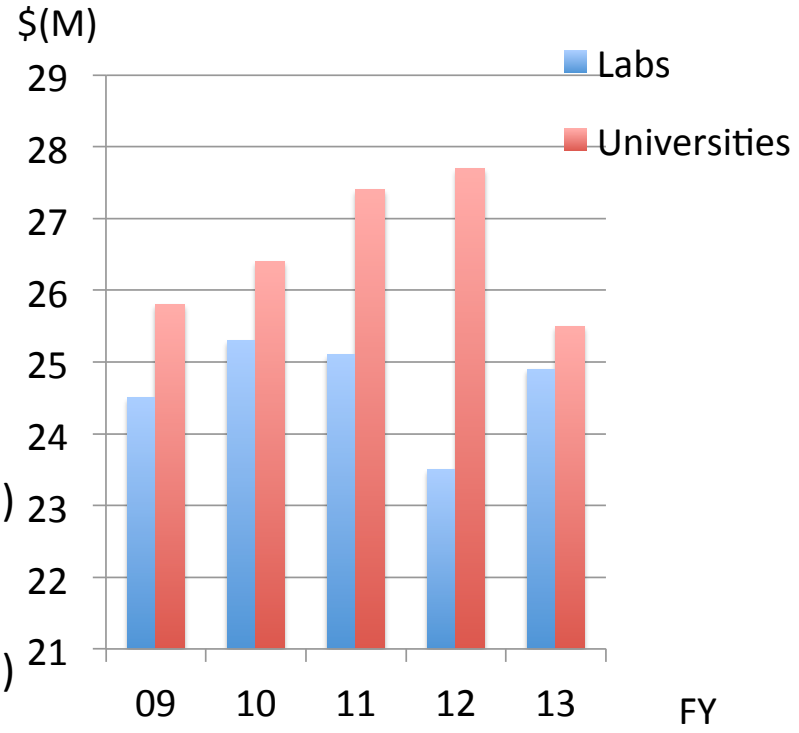
Postdoc and student support are particularly vulnerable: hiring a research associate requires some minimum funding level, and many groups are likely to find their funds fall below this minimum. Additional cuts to graduate student support will lead to shrinking numbers of individuals admitted to study particle theory, as well as a longer time to Ph.D. for those who remain.

The new comparative review process at the DOE, and the existing review processes at NSF have the potential to allow more targeted cuts, allowing for some control of the numbers of postdocs and students, but even then, serious harm will occur if current budget trends continue.

DOE Theory budget (from Simona Rolli); further cuts anticipated in next three years

office of
high energy physics

- 2009
  - Labs 24,500M
  - Universities 25,800M*
- 2010
  - Labs 25,300M
  - Universities 26,350M *
- 2011
  - Labs 25,100M
  - Universities 27,400M** (26,972M)
- 2012
  - Labs 23,600M
  - Universities 27,700M **(25,232M)
- 2013
  - Labs 24,950M
  - Universities 25,500 *



* Does not include EC

**Universities numbers include EC

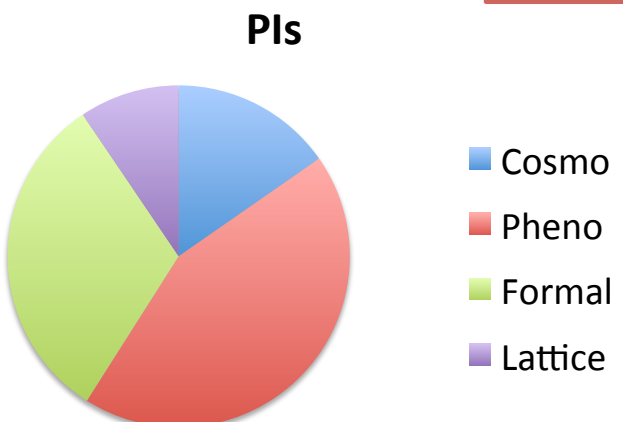
DOE Theory Demographics (from Simona Rolli)

high energy physics

- Comp Rev 2012: 45 PI
  - Cosmo 12
  - Pheno 16
  - Formal 16
  - Lattice 1
- Comp Rev 2013:114 PI
  - Cosmo: 16
  - Pheno 57
  - Formal: 31 passed
  - Lattice 14 passed
- Comp Rev 2014: 58 PI
  - Cosmo 6
  - Pheno 24
  - Lattice 5
  - Formal 23

Postdocs: 95 FTE (0.43/PI)
Students : 122 FTE (0.55/PI)

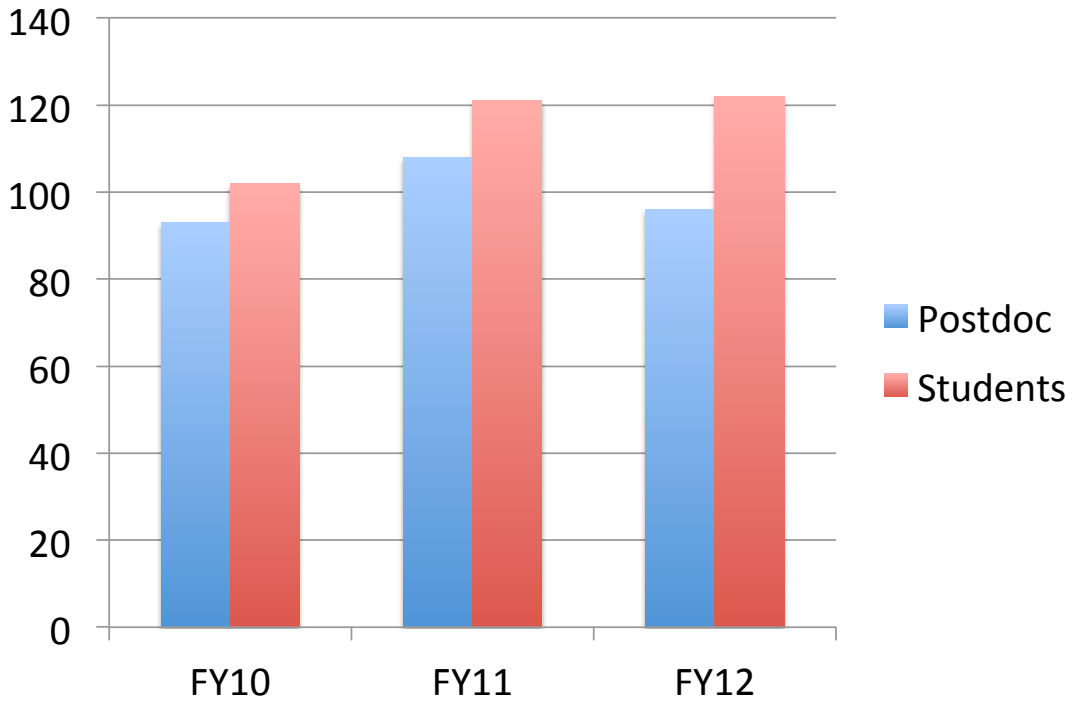
Total: 221 PI
Cosmo 34
Pheno 97
Formal 70
Lattice 20



NSF numbers (unofficial): 186 PI's and approximately 50 postdocs and 50 grad students

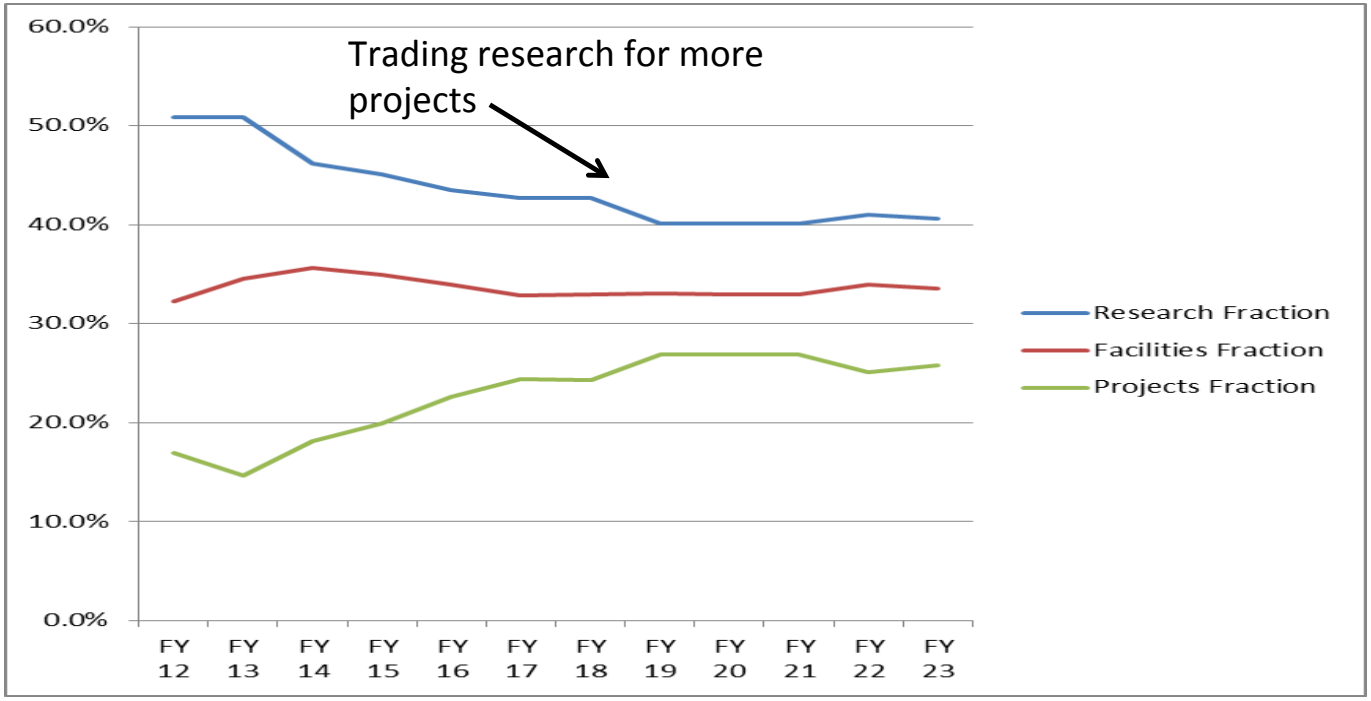
DOE Postdoc and Student support comparatively flat

high energy physics



Future trends

- Not promising.



Panel recommendations: Several, but I would hope P5 would focus on sustaining something close to the current level of postdoc and student support.

- At DOE, the challenges for theory funding arise, in part, from the decision to move more funds to *projects*. While we support this, the affects on theory are profound, as there are few project categories. At NSF, cuts to theoretical particle physics have been particularly severe recently.
- **Proposal: special funding to provide postdoc support, modeled, very loosely, on European networks. Groups of institutions would propose programs, 3-5 years, judged competitively. Scale might be five postdocs, similar number of students. One-two such programs/year.**
- **Alternative (COV): special postdocs, analogous to LHC or Hubble fellowships, awarded competitively. [Both possibilities could be implemented by DOE and/or NSF]**
- **Perhaps some of this money from project/research realignment; some (COV proposal] from resources which become available as Bridge funding no longer necessary.**

What do we hope for from P5?

- Assertion of the important role of theory, and of the strength of the U.S. program
- Recognition of difficulties of current funding environment
- Endorsement of proposals for funding from DPF panel or COV (for networks, new postdoc funding), or other alternatives, particularly aimed at sustaining healthy postdoc and grad student cohort.